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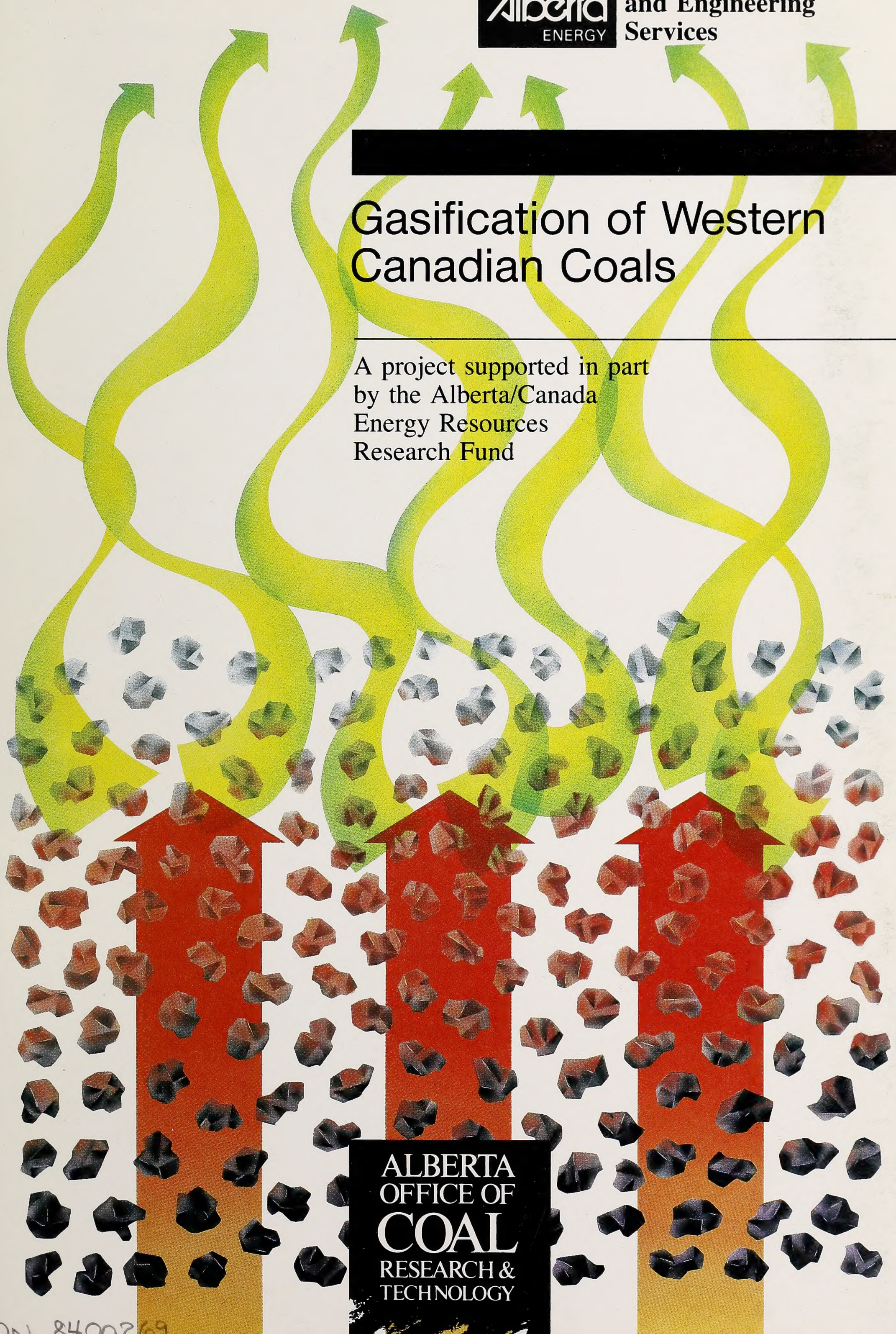
Gasification of Western Canadian Coals

A project supported in part
by the Alberta/Canada
Energy Resources
Research Fund



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1988
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Alberta
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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal and conventional energy resources, as well as energy conservation and renewable energy. Program administration is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy.

In recognition of the importance of coal to Alberta's economy, the Alberta Office of Coal Research and Technology was established in 1984 within Alberta Energy and Natural Resources (now Alberta Energy). Its primary purpose is to encourage the development and application of new technologies related to Alberta coals. The Office provides funding contributions to research and development projects in industry, academic institutions and other research establishments and monitors their progress in an overall program of improving the production, transportation and marketability of Alberta coals.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page 14.

Gasification of Western Canadian Coals

During 1985/86, the Alberta Office of Coal Research and Technology spearheaded the development of a joint industry/government research program on coal combustion. Out of this effort grew an awareness that considerable activity was occurring in several countries, particularly in Japan, on the development of coal gasification technologies.

Consequently, an Alberta coal gasification research program began to take shape, with broad objectives of evaluating the various technologies and the suitability of using Alberta coals in a range of gasification systems.

As a first step in this program, a review was made of current coal gasification technologies. This included a determination of the properties of coals required by these systems and an investigation of opportunities to use the various technologies in Canada. The review also examined the potential of selling coal for use in these processes in Canada and other countries.

The investigation was carried out by TransAlta Utilities Corporation, with Monenco Consultants Limited of Calgary as the principal subcontractor. Funding was provided by the Alberta/Canada Energy Resources Research Fund (through the Alberta Office of Coal Research and Technology), Alberta Power Limited, Luscar Ltd., Saskatchewan Power Corporation and the Atlantic Coal Institute. The final report, entitled "Gasification of Western Canadian Coals," was completed in February 1987.

Background

The concept of coal gasification is now new. It was used as a method for producing fuel gas and chemicals long before the use of petroleum and natural gas for these purposes became commonplace. What is new is the improved technology used in some applications of the process, coupled with the realization that petroleum and natural gas reserves are declining, while coal continues to be abundant in many countries. Gasification also permits coal to be used in such a way that air-polluting emissions are only a small fraction of those now associated with coal combustion processes. Hence, widespread use of coal gasification could usher in a new era of coal use characterized by few, if any, negative stigmas associated with coal combustion. Therefore, because coal gasification is a relatively clean process, its use could allow economic development to occur without sacrificing the aims of environmental protection.

Gasification processes convert coal into a mixture of gases by contacting the coal with air, oxygen or steam in a reactor at elevated temperatures and pressures. The exact composition and heating value of the gas mixtures are determined by coal composition and gasification conditions, but the gas usually contains hydrogen, nitrogen, water vapour, carbon monoxide, carbon dioxide, methane and hydrogen sulphide.

The most important chemical reactions that occur are:

$$\begin{aligned}
C + O_2 &\longrightarrow CO_2 \\
C + \tfrac{1}{2} O_2 &\longrightarrow CO \\
C + H_2O &\longrightarrow CO + H_2 \\
C + CO_2 &\longrightarrow 2\,CO \\
H_2O + CO &\longrightarrow H_2 + CO_2 \\
CO + 3H_2 &\longrightarrow CH_4 + H_2O \\
C + 2H_2 &\longrightarrow CH_4
\end{aligned}$$

The gaseous products of these reactions can be: (1) burned directly; (2) processed to remove acidic components; or (3) upgraded for some applications.

The three principal types of gasification processes are: (1) fixed bed; (2) fluidized bed; and (3) entrained flow.

Study Approach

In the TransAlta investigation, the status of current coal gasification technologies was reviewed, possible uses for the technologies in Canada were determined, the potential for overseas sales of western Canadian coals was evaluated, and those coal properties most important for gasification purposes were ascertained.

It was determined that the most significant uses for coal gasification are:

- to generate power, using integrated gasification combined cycle (IGCC) plants;
- to generate synthesis gas (CO/H_2), which serves as a feedstock for chemical manufacture;
- to produce low and medium heating value fuel gas; and
- to generate substitute natural gas (CH_4).

To determine how significant each of these uses is, or will be, in other countries, and the prospects for such applications in Canada, it was first necessary to evaluate the available coal gasification technologies.

For example, it was found that 13 fixed bed gasification processes exist, in which coal moves slowly through the bed within the gasifier. Six processes thought to be capable of commercial production by the mid-1990s were studied in detail. They were: (1) Ruhr 100; (2) British Gas Corporation (BGC)/Lurgi; (3) Allis Chalmers' Kiln gas; (4) Kohlgas Nordrhein GmbH (KGN); (5) Lurgi; and (6) Wellman-Galusha.

Similarly, 12 fluidized bed processes were identified, of which six were analysed. In every case, gasifying air and steam enter through the bottom of the reactor with sufficient velocity to cause the reactor bed to behave like a fluid. The process is characterized by a constant temperature throughout the bed and continual mixing of the coal feed and partially gasified material.

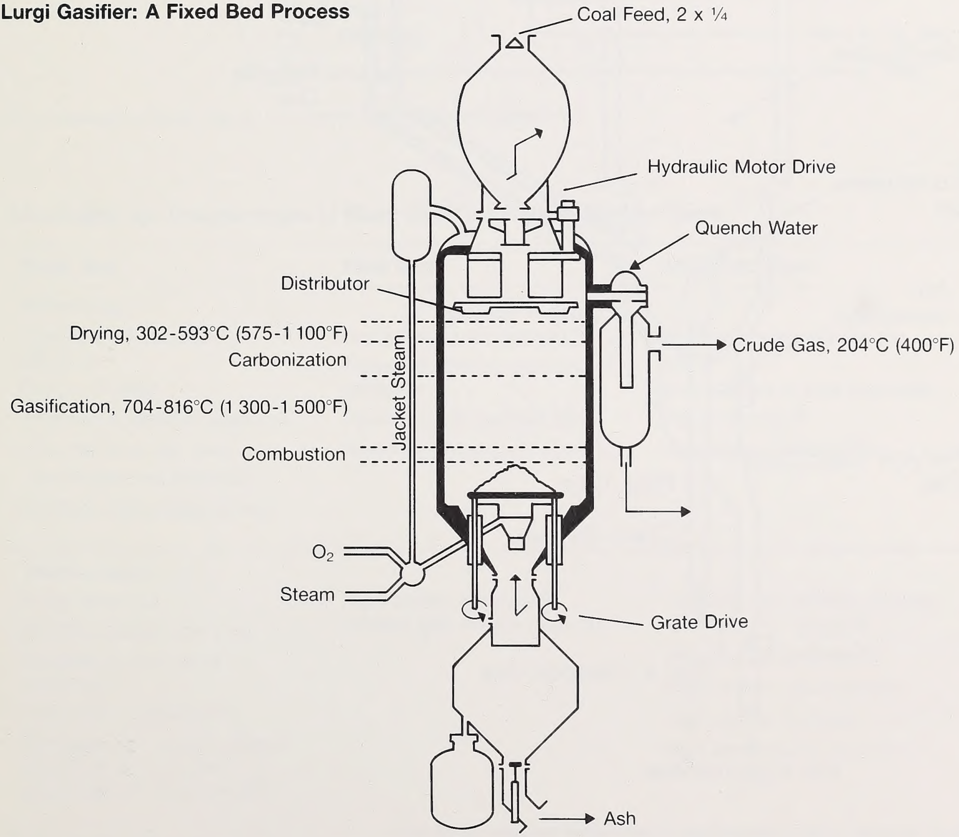
The processes which were evaluated were: (1) Coal Mining Research Centre, Japan (CMRC); (2) Institute of Gas Technology (U-Gas); (3) high temperature (HT) Winkler; (4) Kellogg-Rust-Westinghouse (KRW); (5) Lurgi CFB; and (6) Hitachi Ltd.'s Hybrid Gasification.

Thirteen entrained flow processes were identified; five were evaluated in detail. These processes permit rapid reaction of finely ground coal, oxidant and steam at high temperatures (approximately 2 000°C) to produce a gas free from tar or oil, which is primarily carbon monoxide, carbon dioxide and hydrogen.

The systems which were studied in detail were: (1) Texaco; (2) Shell; (3) Mountain Fuel Resources (MFR); (4) Krupp-Koppers GmbH PRENFLO; and (5) Dow.

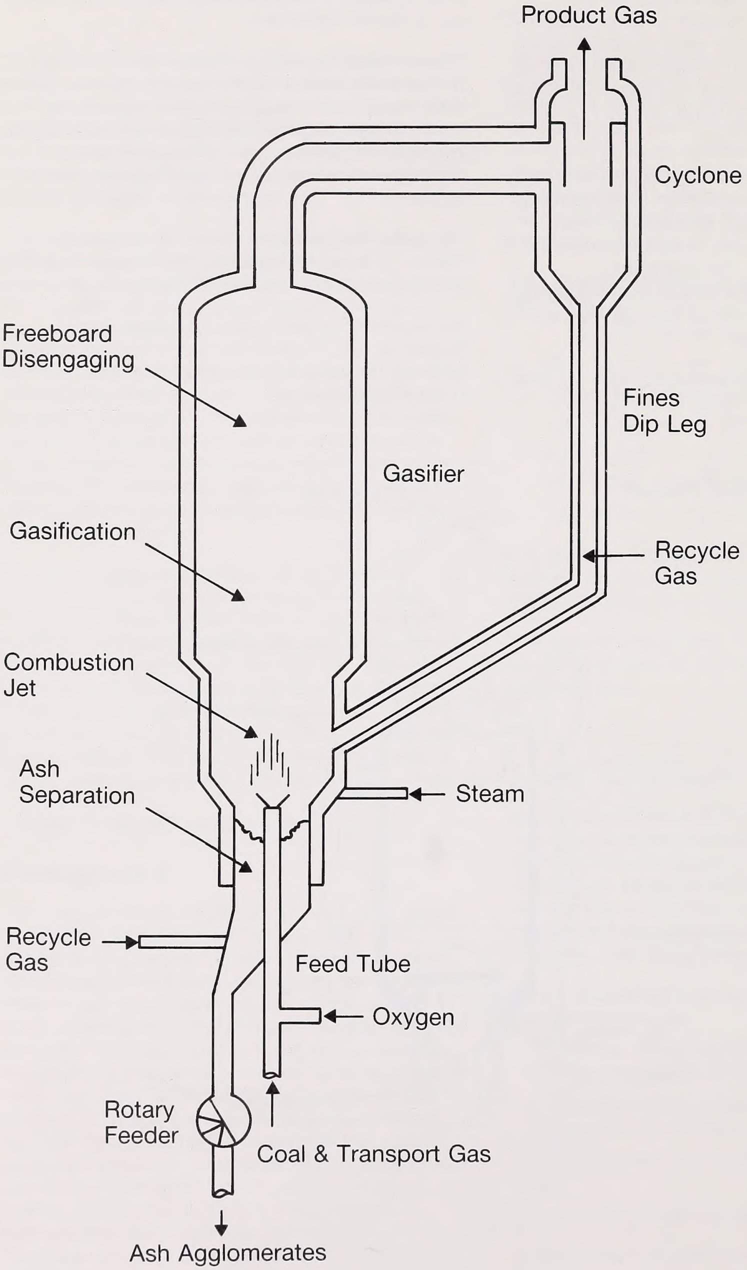
Six experimental gasification processes were studied as well, involving such concepts as plasma arcs and molten salt baths. Most have been tested in the laboratory only.

Lurgi Gasifier: A Fixed Bed Process



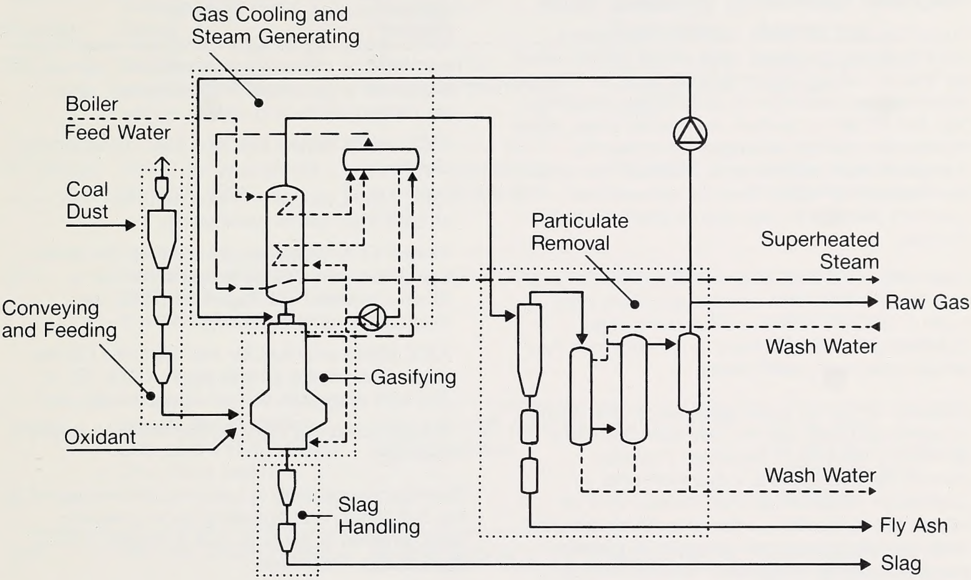
(Source: *Gasification of Western Canadian Coals,* TransAlta Utilities Corporation, January 1987)

Kellogg-Rust-Westinghouse Gasifier:
A Fluidized Bed Process



(Source: *Gasification of Western Canadian Coals*, TransAlta Utilities Corporation, January 1987)

PRENFLO Gasifier: An Entrained Flow Process



(Source: *Gasification of Western Canadian Coals,* TransAlta Utilities Corporation, January 1987)

Advantages and Disadvantages of Major Coal Gasification Reactor Types

Fixed Bed	Fluid Bed	Entrained Flow
Advantages		
· High inherent process efficiency · Design simplicity · Extensive operating experience · Low coal fines carryover · Low oxygen requirements · Relatively high methane yield	· Limited or no tar formation · Moderate inherent process efficiency · Operates with crushed coal · Moderate temperature operation	· High coal consumption per vessel · Not sensitive to coal properties · No tar formation · Low steam consumption
Disadvantages		
· Small vessel size · Cannot process coal fines · Sensitive to coal-caking properties · High steam consumption · Produces high-sulphur content tar and oil and reactive by-products such as phenol	· High carbon carryover in product gas; recycle required	· Relatively low inherent process efficiency · Requires pulverized coal · High oxygen requirements · High carbon carryover · High temperature operation

(Source: *Gasification of Western Canadian Coals,* TransAlta Utilities Corporation, January 1987)

Applications

Integrated Gasification Combined Cycle

During the past 20 years, electricity-generating systems called combined cycle power plants, which are fired by natural gas or light oil, have demonstrated a number of advantages, including high fuel efficiency, relatively low capital costs, short construction periods and rapid responses to changes in load requirements. However, fuel costs have been much higher than for conventional coal-fired plants and have been subject to rapid changes.

Meanwhile, projected increases in energy demand have been smaller than anticipated, which has made it difficult for those utilities using large, coal-fired generating stations to decide when they should build new power plants.

Because combined cycle plants are smaller than conventional power plants, they allow electricity-generating capacity to be added in smaller increments. Furthermore, if gas from coal gasification processes is used instead of oil or natural gas to fire the combined cycle system, fuel costs can be lowered and stringent air pollution standards can be more easily satisfied than is possible with conventional coal-fired plants.

In a conventional IGCC system, coal is gasified at high temperature and pressure. The high temperature raw gas is cooled in a heat recovery boiler and is then cleaned to remove particulates, sulphur and other undesirable components before being fired in a gas turbine.

Exhaust gases from the gas turbine are passed through a heat recovery system steam generator before being vented to the atmosphere from a stack. Steam from the heat recovery steam generators is passed to a steam turbine. The resulting power and the power produced by the gas turbine are fed to the grid.

The advantages of IGCC systems are:

- potential environmental contaminants can be removed from the fuel gas at a relatively low incremental cost;
- particulate emissions have been shown to be well below emission control requirements;
- solid wastes from the system are primarily limited to coal ash. No sludge is generated as in flue gas desulphurization (FGD) systems;
- IGCC plants require significantly less water than conventional plants. Approximately 67 per cent of the power is generated in gas turbines, which do not require cooling water;
- IGCC plants require less land than conventional plants;
- IGCC plants can be as much as 10 per cent more efficient than conventional plants;
- mature IGCC plants are said to have the same capital requirements as conventional plants. When combined with higher efficiency, this means lower-cost electricity;
- IGCC plants are modular and comprise parallel trains. This means smaller plants in the 100 to 200 MW range can be built economically; and
- it is expected that modular plants will be readily available.

Seven processes likely to become commercialized by the mid-1990s, and operating under pressure, were reviewed in detail for their suitability in IGCC applications. They were:

BGC/Lurgi *(Fixed Bed)*

High Temperature Winkler
KRW
(Fluidized Bed)

Texaco
Shell
PRENFLO
Dow
(Entrained Flow)

Each process was evaluated according to 10 parameters, such as development status, inherent emissions, gasifier pressure and efficiencies.

Two processes — Texaco and BGC/Lurgi — were selected as good candidates for near-term applications (to 1990), while it was thought that KRW, Dow, Shell and PRENFLO could become viable commercial processes by 1995.

Development Status of Gasifier Systems

Process	Development Status	Feedstock Flexibility	Gasifier Temperature	Assessment
BGC/Lurgi	550t/d commercial unit supplies 30MW gas turbine	Developed for unreactive bituminous coal	Up to 2 000°C in slagging zone	Good potential for near term
HT Winkler	700t/d commercial unit started in 1986	Limited to reactive non-caking low rank coals	750-850°C	Limited experience. Needs development.
KRW	Pilot unit operating since 1972. 440t/d, 60MW plant due 1989	Wide range of coals	850-1 050°C	Many advantages. Good candidate for medium term if built on a commercial scale.
Texaco	Several demonstration units plus 910t/d, 100MW Cool Water project	Low rank, high moisture coal not suitable	Up to 2 000°C	Can be used immediately, but may be overtaken by other processes
Shell	Pilot, but 250t/d in 1987	All ranks of coal	Up to 2 000°C	Commercial-scale demonstration under construction.
PRENFLO	Pilot scale, but 1 000t/d expected in 1988	All ranks of coal; up to 40% ash and high moisture	Up to 2 200°C	Commercial-scale demonstration under construction.
Dow	1 600t/d; 2 200t/d under construction	Developed especially for subbituminous or lignite coals	Up to 2 000°C	May have better efficiency than other entrained flow processes, Medium-term project.

(Source: *Gasification of Western Canadian Coals,* TransAlta Utilities Corporation, January 1987)

Low and Medium Heating Value Fuel Gas

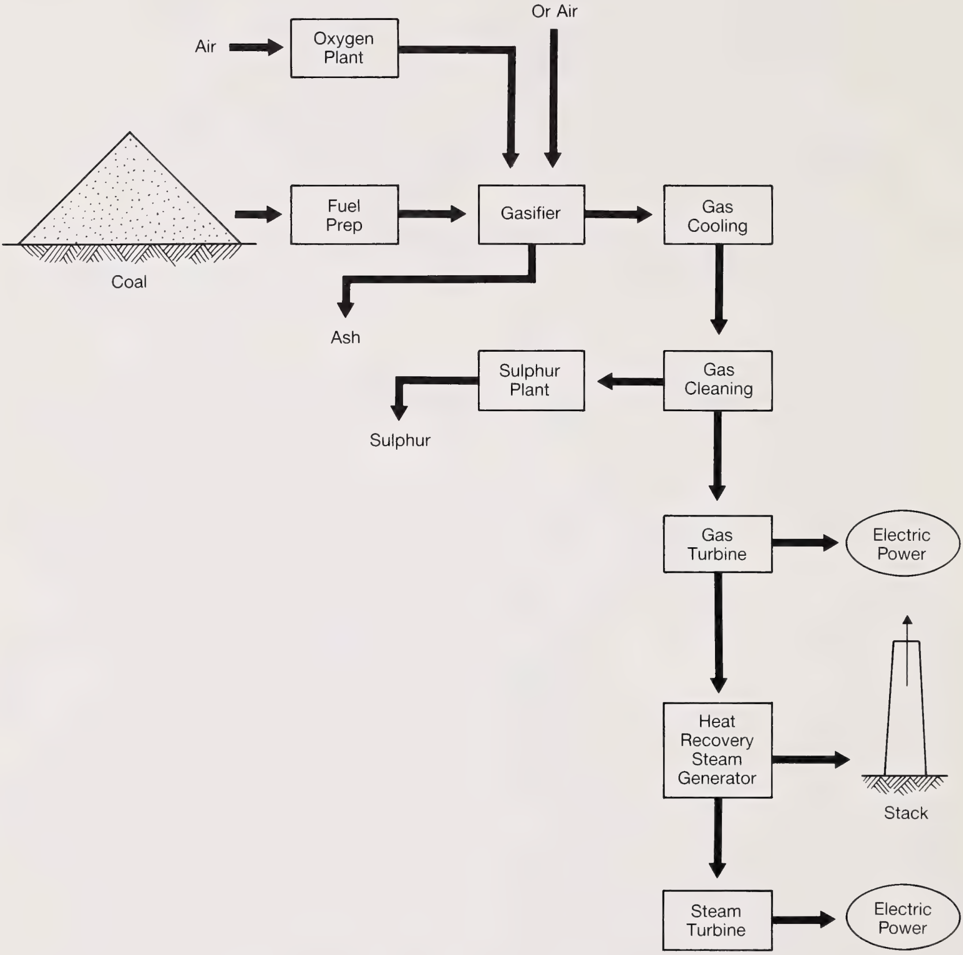
In the 1930s, thousands of small gas production systems were used to produce industrial fuel gas. Today, coke oven gas and blast furnace gas are still used widely in the steel industry. The potential market for this type of fuel continues to be large because of widespread oil and gas firing in high density industrial areas.

Two types of fuels were considered in this investigation: (1) medium heating value fuel gas (10 to 12 MJ/m^3) produced at a central plant and then transported by pipeline to clients; and (2) low heating value fuel gas (3.8 to 6.5 MJ/m^3), which is usually produced near the point of use.

The use of fixed bed and fluidized bed gasifiers for production of coal-derived fuel gas was examined in some detail, but entrained flow gasifiers were ruled out because they require an extensive heat recovery system, and operation is complicated by carbon hold-up.

It was concluded that even the least expensive systems produced fuel gas at costs several times greater than for natural gas.

IGCC System Schematic



(Source: *Gasification of Western Canadian Coals*, TransAlta Utilities Corporation, January 1987)

Substitute Natural Gas

Substitute natural gas (SNG), which is similar to natural gas and is mostly methane, is produced by upgrading medium heating value fuel gases.

Lurgi is the most notable SNG process. The only North American plant is the Great Plains Project in North Dakota, which uses 14 Lurgi gasifiers having a total designed production capacity of 3.88 million m^3/day of SNG from lignite.

An analysis of this operation revealed that it was successful, but uneconomic.

Synthesis Gas

For at least 50 years, coal gasification processes have been used to produce synthesis gases, which are used to make hydrogen, methanol, ammonia, acetic anhydride, gasoline and liquid fuels.

In recent years, coal gasification plants have been built in the U.S. and Japan to produce ammonia and acetic anhydride. The SASOL I, II and III plants in South Africa produce liquid transportation fuels and other chemicals from subbituminous coal.

An examination of operations in these three countries revealed that the technology is both successful and reliable, but the process economies are dependent on the price of coal relative to other fuels; in at least one case it was more expensive to use coal.

Most Promising Application

Of all the applications for coal gasification that were investigated in this study, it was concluded that IGCC offers the best prospects for successful, large-scale operations by 1995. On the other hand, the production of synthesis gas, substitute natural gas and low or medium heating value fuel gas from coal gasification was viewed as unlikely, unless the prices for alternative fuels rise sharply. Nevertheless, the processes themselves are both available and technically viable.

Desirable Coal Properties

Gasifiers differ in their ability to convert various types of coal and coal fines, and they operate best when fuelled by coals having certain properties. These desirable coal characteristics are similar to those required by pulverized coal-fired boilers.

The ratio of fixed carbon to volatile content, as determined from *Proximate and Ultimate Analysis,* is a good indication of reactivity. The desired ash content is a direct function of the capability of the ash removal system, while moisture content affects the amount of air or oxygen that is required for gasification.

Fixed bed gasifiers are not as sensitive to the *Hardgrove Index* of coals as are entrained flow processes, which require a grind similar to pulverized coal-fired boilers.

Caking, as indicated by the *Free Swelling Index,* is not a problem in entrained flow designs, but coals exhibiting this property are generally not suitable for use in fixed bed or fluidized bed gasifiers.

As-Received Size Distribution is important because it determines the amount of preparation required before feeding to the gasifier. Also, some gasifiers can handle only certain amounts of fines.

For dry ash fixed bed and fluidized bed processes, high initial deformation temperatures, as indicated by *Ash Fusion Temperatures,* are required to avoid agglomeration of the ash and maintain a free flow of dry ash. Entrained flow processes, however, require a low fluid ash temperature to reduce the gasifier operating temperature, to minimize the conversion of carbon to carbon dioxide and to minimize the consumption of air or oxygen.

In many cases, the life of refractory lining used inside gasifiers is governed by the corrosion/erosion action of slag. This is indicated by the *Ash Chemical Analysis.*

A method of evaluating the suitability of coals for gasification purposes is being developed by the Central Research Institute of the Electric Power Industry in Japan for an entrained flow gasifier design.

It involves plotting fuel ratio against ash-melting temperature. When these particular properties were plotted for Alberta coals, representing the Horseshoe Canyon and Paskapoo formations and the foothills and mountain regions, it was found that three of them were suitable, but Smoky River coal representing the mountain region probably would not be suitable for this particular entrained flow gasifier.

Overseas Market Potential

Given the observation that most Alberta coals should be suitable for gasification systems, and that the most attractive application of these technologies is to generate power in IGCC systems, market opportunities for Alberta coals were evaluated in Japan, South Korea, Taiwan, Hong Kong, Philippines, Thailand, Malaysia, Singapore and Indonesia.

During this phase of the investigation, it was noted that the only way for coal sales to increase was if IGCC systems were built in place of power-generating processes that were fuelled by energy sources other than coal. If IGCC systems simply replace conventional coal-fired plants, coal sales would decline because an IGCC system requires approximately 80 per cent as much coal as a conventional coal-fired plant for the same output.

From this analysis of prospective opportunities in Pacific Rim countries, it was concluded that:

- Japan has plans to introduce IGCC technology, but prospects for coal sales are in the medium term (approximately by the year 1995) only. By the year 2000, however, a 2000 MW plant may be operating, which will require 3.2 million tonnes of coal a year;
- currently, large quantities of liquefied natural gas (LNG) are used in Japan to generate electricity. If all LNG power plants were replaced by IGCC plants, this would represent a market potential equivalent to 55 million tonnes of coal a year by 1995;
- there are no apparent coal gasification prospects in Hong Kong, Philippines, Singapore and Indonesia;
- there is a possibility that gas-fired combined cycle power plants may be installed in Thailand and Malaysia, to which coal gasifiers might be added later;
- although air emission standards in South Korea and Taiwan are lax, concerns about air quality are not yet causing any interest in IGCC systems; and
- if IGCC technology develops to the point where it is competitive in cost with conventional coal combustion without flue gas desulphurization, it could displace conventional coal firing, but this would result in less coal consumption.

Recommendations

Taking all of this information into consideration, the investigators recommended that IGCC developments should be monitored closely, assessments should be made of IGCC technology for use in Canada, and Alberta coals should be made available to the developers of Japanese IGCC systems.

The following specific recommendations were made:

- screening curves should be developed for low heating value and medium heating value fuel gases in industrial applications to identify economic cost regimes for future applications;
- cycle performance calculations for IGCC systems should be carried out, which are appropriate for applications in Alberta;
- the effects of low sulphur content Alberta coal on gasification costs and economics should be assessed;
- coal property data and published gasification test data should be reviewed to determine how well gasification performance can be predicted from coal analyses;
- a pool of Alberta coal should be provided in Japan for testing in various gasification processes under development;
- any changes to environmental legislation in Pacific Rim countries should be monitored;
- possible IGCC and industrial fuel gas applications in central Canada and the Maritime provinces should be reviewed;
- the concept of coal gasification should be promoted not only for its own merits, but also because its widespread use would release more natural gas for export sales; and
- the costs of IGCC plants in Pacific Rim countries should be estimated to determine if any economic advantages apply to smaller, more efficient plants, compared with conventional coal-fired power plants.

Subsequent Developments

Based on the findings and recommendations of the TransAlta study, the Alberta Office of Coal Research and Technology is spearheading a National Coal Gasification Technology Research, Development and Demonstration Program, in which industries and governments from across Canada are invited to participate.

It is believed such a program is warranted because IGCC technology represents a substantial improvement over current coal-fired electricity-generating plants, especially in terms of air emissions, and Canada as a whole has large coal reserves, which could be used in domestic and overseas markets. In addition, it is thought that coal gasification represents another way of diversifying energy supplies for large-scale consumers, and it could contribute to Canada's goal of energy self-sufficiency.

So far, three major objectives have been identified for the program. They are:

- by 1994, to design and build a 150 MW (electrical) prototype IGCC plant in Canada;
- to establish and standardize coal gasification testing methods for Canadian laboratories; and
- to facilitate performance evaluations of Canadian coals in the various coal gasification technologies suitable for Canadian industry.

Program Structure

Five major elements of the program have been proposed. They are:

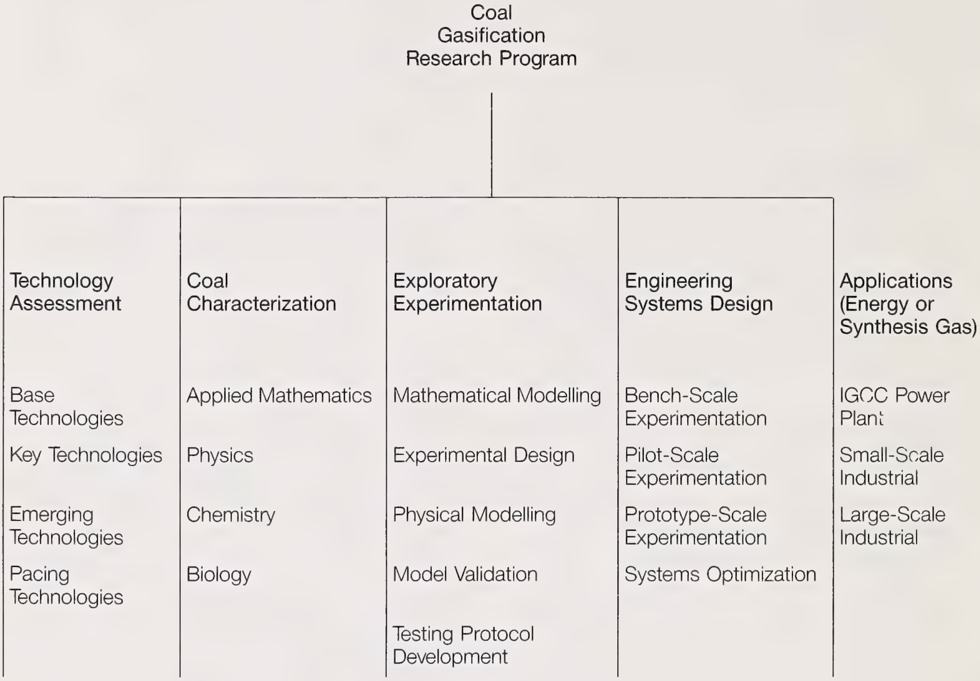
- technology assessment;
- coal characterization;
- exploratory experimentation;
- engineering systems design; and
- applications research.

Some projects are currently underway in all the elements of the program, but this effort is not co-ordinated and does not include some critical areas of investigation. It is proposed that projects should focus on each of the major steps involved in preparing coal as ~~feedstock for an~~ IGCC plant, as well as on each component of the gasification process.

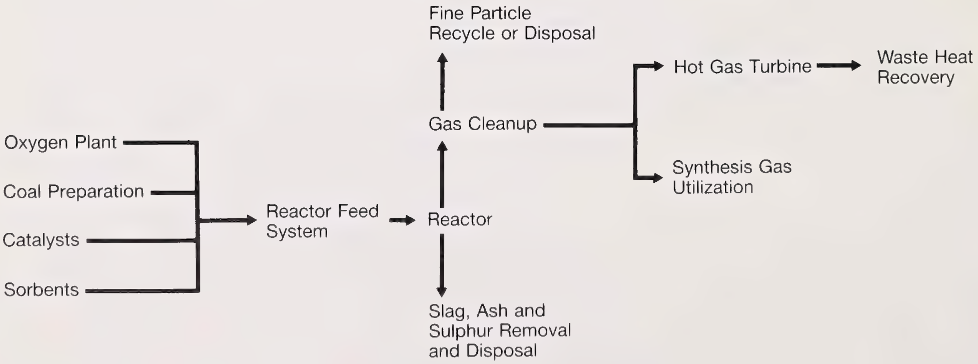
Already, the Alberta Office of Coal Research and Technology is providing partial funding for six gasification projects on a 50:50 cost-sharing basis with industry. It is proposed that this arrangement be used in any research projects included within the National Coal Gasification Technology Research, Development and Demonstration Program.

By becoming involved in the program, participants will join a forum for technical information exchange, provide funding for projects of common interest, contribute to the establishment of national goals and priorities, and participate in projects carried out co-operatively with international firms and agencies. In this manner, Canadians can be at the forefront of technical developments in coal gasification.

Proposed Elements of National Coal Gasification Technology Research, Development and Demonstration Program



Potential Research Topics



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